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GEOTHERMAL ENERGY EXPLORATION

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GEOTHERMAL ENERGY EXPLORATION

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1. - Geothermal energy : a large source of low cost energy.

Temperature surveys of deep wells and deep mines indicate large differences in temperature gradients in the earth's crust. Temperature gradients vary both in the vertical and in the horizontal. In the vertical, the temperature increases with the depth at a roughly average rate of 1 °C per 27-60 m in the sedimentary basins; but in determined areas this value - the reciprocal of the geothermal gradient - can be as high as 1 °C per few meters. Such areas are defined as hypergeothermal areas. The heat's flow can be very large also at shallow depths.

The energy of the hyperthermal areas can be exploited, and actually it is exploited in different regions of the world. Natural heat is a large and very cheap source of energy and the geothermal industry overpassed the initial experimental phases in the last years; a geothermal power plant - as well as other geothermal prospects - can now be considered as an usual prospect, involving no more risks than the average mineral industrial prospects.

The natural heat of the hypergeothermal areas is exploited by drilling a suitable number of wells at a depth between 300 m and 2000 m. The wells can produce three kinds of exploitable fluids: overheated steam, steam mixed with boiling water and hot water.

The wells producing overheated steam and steam mixed with boiling water are currently exploited for the production of electric power. The hot-water wells are exploited for heating purposes and actually they are of less industrial significance, but we must remember that also hot water can produce electric power.

The natural steam can be admitted directly into the turbine-generator units exhausting into the atmosphere (non condensing turbine) or into a vacuum created by condensing the steam in a condenser just after it leaves the turbine (condensing turbine).

When the natural steam, as produced by the wells, is dirty or mixed with a large amount of non-condensable gas, the steam passes in a heat exchanger where steam is generated from condensate water. This "secondary steam" is fed into the turbines.

Various geothermal fields are exploited in the world at present; many others are known in a number of countries and could be developed in a short time.

The three major operating plants are: Larderello (Italy), which produces yearly 2,3 billions of kWh (year 1962); Wairakei (New Zealand), which has been generating power since November 1958 and where a 69 MW plant was completed in 1960 with additional 123 MW to be operating in 1963; The Geysers (California), which is producing power since June 1960 by a 12,5 MW plant, that will be doubled in 1963.

Other minor plants are operating or have been planned in different countries: in Monte Amiata (Italy), in Pathé (Mexico) a turbine of 3.500 KW, in Katanga (Congo); in Kamchatka (U.R.S.S.).

In Japan, Chile, El Salvador, Kenya, exploration and drilling are under way. Important exploration works are currently conducted or anticipated in Italy, New Zealand, U.R.S.S. and U.S.A..

We think that the largely delayed expansion of the geothermal industry will take place in the near future. The production of electric energy from the geothermal fields already in operation will augment, namely in Larderello, Wairakei and The Geysers. Drilling will be more active in various known fields and the building of power plants will follow as soon as the steam production will reach a convenient figure.

The main reasons for such a confidence are three:

1. - A few years ago, geothermal energy was largely ignored or considered an exceptional event; now, it is a common topic of scientific and industrial information.

2. - Great progress has been registered in all phases of the geothermal science, from exploration to production; substantial reduction of cost and risks have been already accomplished.

3. - The cost of the geothermal KWh is no more a matter of guessing; the experience obtained by the three large plants operating for years authorizes us to calculate in advance the expenses and the production costs in a new field with errors of the same order as in a new oil field.

The kWh cost in Larderello is about 3-4 mills ($ USA); in Wairakei, 4.5 mills and it will probably be reduced.

The actual cost of the hydroelectric and thermal kwh produced by the largest power plant varies from 4 to 10 mills. The lower figures are those of some privileged hydroelectric power plants.

It is no doubt that the geothermal energy is a large source of very low cost energy, and possibly the lowest cost energy now available.

2. - Three geothermal fields: Larderello, Wairakei, The Geysers.

A very brief description of the three main fields now in exploitation will give a better understanding to the reader.

a.- Larderello. Larderello lies in Tuscany (Italy), west of Siena, halfway between Siena and the Thyrrenian Sea. It was known for centuries for its hot water and steam jets temperature from 100° to 190° C,(average pressure 5 atm),utilized for the boron industry.

In 1905, the first power plant working with geothermal energy ignited 5 bulbs; large industrial electric development occured between the two World Wars; after World War II, the chemical production at Larderello was economically negligible and the electric production overwhelming.

The geology is summarized in the cross-section of fig. 1. The basement is quartzitic and anagenetic; follows an ingressive, Upper Triassic, evaporitic-dolomitic series, with high porosity and permeability. It is the steam producing series.

The evaporitic series is unconformably overlain by a flysch-like, shaly, impervious series, locally called 'Argille Scagliose", of Upper Cretaceous-Lower Miocene age.

Nearly all Italian geologists retain that the Argille Scagliose Series is allochtonous; this is not the place to discuss the point, because its significance in the comprehension of the geothermal field is limited. We limit us to point out the different structural behaviour of the upper impervious series in comparison with the lower evaporitic and dolomitic reservoir series. The former is plastic and its reactions to the basement's movements are of the gravitational tectonic type, whereas the lower, more rigid series presents a fault-block structure.

As a consequence, the structure of the producing series can not be inferred from the structure of the Argille Scagliose Series. The fault and fracture areas can be detected only by geophysical surveying and by drilling.

Owing to the space limitation, we cannot give a satisfactory geological description.

We can only point out some interesting geological features of the Larderello field:
1. - In the Larderello area, recent volcanoes do not exist. The abnormal heat flow is provided by a magma stock laying at unknown depth.

2. - The temperature at the top of the producing series is over 200°C and does not sensibly increase with depth in the pervious series. This evidence strongly indicates convection currents in the waters of the producing series.

3. - Hot waters, steam jets and other surface signs of hyperthermal conditions occur near the out-crops of the lower pervious series or where the Flysch series has a very limited thickness. No industrial steam production is recorded where the producing series out-crops. From this and many other evidences, we can safety conclude that an impervious cover is a sine-qua-non condition in the natural superheated steam production.

4. - A great number of geologists believed in the past that the steam was separated by a granitic cooling magma stock and fed trough faults in the producing anhydritic series. They believed also that the producing series contained steam. In the very last past years, this view was consistently proved untenable. The producing series contains meteoric water with the temperature not over the boiling point corresponding to the hydraulic pressure.

A limited amount of magmatic fluids is still postulated by some Authors, who explain the superheating in such a manner.

Tonani and the present writer offered different explication of this intriguing point.

5. - Fig. 2 indicates that scattered areas are at present exploited in the Larderello geothermal field. Three wells recently drilled outside those areas are very good producers; they offer evidence that the true possibilities of the Larderello field are not yet entirely recognized. We can suspect that the field is many times larger than believed; the last successful wells open a new phase in the Larderello field exploration.

The present writer believes that any area of the Larderello region, where we can reasonably suspect that the Anhydritic Series lies at a depth not exceeding 1500-2000 m and is pervious, is a drillable prospect.

The Mount Amiata field lies about 60 km southeastward of Larderello. The geological series and structure are nearly the same as in the Larderello field.

In two points, however, the Monte Amiata field differs from the Larderello field.

First, in Monte Amiata, surface signs of abnormal heat are limited to some hot sources (20°-50°C) CO2 and H2 S mofettes and mercury ore.

Second, Mount Amiata is an extinct quaternary volcano of the acide type, with an extensive ignimbrite cover.

The marine Pliocene sediments occur at 900 m elevation and give evidence of very recent tectonic activity, related to the upward movement of a magmatic mass, now cooling near the surface, but in any case at considerable depth.

b. - Wairakei. The Wairakei geothermal field lies south-east of the Bay of Plenty, in the Northern Island (New Zealand). It is a volcanic region 240 km in length, from the center of the island to the Bay of Plenty. Structurally, it is a recent graben filled mainly by vulcanites.

Two andesitic volcanoes, Ruapehu and White Island, are active at each end of the graben; other active basic volcanoes and recently active rhyolite domes dot the graben.

Wairakei field is a complexely faulted horst in the major graben of the volcanic district. But we must point out that the hyperthermal area in the Waiora Aquifer is not limited to the top of the structure: also the depression on both flanks of the horst are productive.

The geothermal exploration and exploitation history in New Zealand is characterized by close and efficient relations between science and industry from the very beginning. The precious experience thus gained has been communicated in a remarkable series of papers, of uppermost importance for the progress of the geothermal science.

In occasion of the U.N. Conference on New Sources of Energy (Rome, August 1961), New Zealand presented a large number of papers, covering every geothermal detail.

Many previous important contributions were published by the "New Zealand Journal of Geology and Geophysics", the N.Z. Department of Scientific and industrial Research Bull., N.Z. Geol. Surv. Bull. and N.Z. Engineering.

More important data are resumed here.

Wairakei has (1961 data) 26 wells on production; 26 more will be on production in 1963. The New Zealand Government authorized an installation of 192 MW of plant, of which the first stage (69 MW) was completed in March 1960. Tentative plans have been prepared for later extending the scheme to a total installated capacity of 282 MW (Armstead, 1961).

"The first plant (69 MW) makes use of bore steam only and employs seven small turbo-alternators of approximately 6 1/2 MW and 11 MW ratings. The second stage (123 MW), now under construction, will introduce to a limited extent the use of hot water in addition to bore steam; it will be also partly served by larger (30 MW) turbo-alternators" (Armstead 1961).

Initial drilling commenced in 1950 and electric power was supplied to the North Island Grid in November 1958.

Temperatures range between 200° and 260°C.

Bottom diameter of the holes is 7 5/8", average depth 1000 m.

A casing is cemented in the lacustrine mudstone series; a suspended liner (6 5/8" or 6") is run on the bottom in the producing formation. It is removable for easy cleaning when the slots become blocked by chemical deposits or rock particles.

Average cost of drilling is about $ 150 per meter.

The range of the total depth is 500-1000 m.

Other geothermal fields in New Zealand are Waiotapu and Kawerau, both of them under development. Many other thermal areas (including also Rabaul, in New Britain) have been recognized and are under investigation.

c. - The Geysers, California, U.S.A.

A total of 43 wells have been drilled in the Western United States for the exploration and exploitation of geothermal power. Drilled areas are The Geysers (now producing electric power by an automatic, 12.500 KW power plant), Casa Diablo (Mono County, California), Calistoga (Napa County, Cal.), Surprise Valley; Cal., Wabusta (Nevada), Steamboat Springs (South of Reno, Nevada), Brady Hot Springs (Nevada), Beowave, (Northern Central Nevada).

Papers of L. Decius and mc Nitt (1961) gives us a full account of the geothermal exploration in U.S..

A full discussion of the behaviour, interpretation and thermodynamic of the field can be found in a paper by Facca-Tonani, published in 1962 in the "Bollettino dell'Osservatorio Geofisico di Trieste". The space limitation forbids us to give here detailed account of this interesting subject.

4. - Exploration: methods and cost

Exploration for geothermal energy shows many analogies with oil exploration; the analogies dealt with the methods (geology, geophysics, drilling) and risk mentality, common to both industries. The main differences lie in the cost (the geothermal exploration is somewhat less expensive) and experience (the geothermal science is less advanced than petroleum science).

Geothermal prospection is generally carried out in 4 stages.

1. - Preliminary survey and selection of an area.
2. - Detailed survey on a selected prospect.
3. - Test drilling.
4. - Probing and evaluating.

Number 1 requires a regional general survey, comprising several stages:

a. - an economic study on the energy requirements and on the regional comparative cost of energy;
b. - a critical study of all available topographical, geological, geophysical and geothermal information;
c. - a detailed survey of the surface thermal shows;
d. - a preliminary servey of the stratigraphical series, with some general information about porosity and permeability, i.e. information about the possible stratigraphical. targets (cover and aquifer);
e. - the choice of the most promising area.

Point 1 requires about six months of work by a very experienced geothermal geologi geologist with the aid of a young geologist.

The range of the cost is in the range of $ USA 18.000-25.000-.

With point 2 begins the detailed reconnaissance, involving the work of several specialists. The most important works to be performed are:

a. - Detailed photogeology and field geology, volcanological studies, petrography and structure;
b. - detailed hydrogeochemistry and geochemistry and hydrogeology;
c. - evaluation of the minimum heat output; extent of the anticipated field;
d. - geophysical survey; each prospect needs a different program: electric, magnetic, gravimetric, thermometric and seismic methods can be useful, in accord with the geological data;
e. - all the above mentioned surveys will indicate a location for the first: exploratory well.

The cost of the operation under point 2 largely varies according to the geophysical program, which is the most expensive of all surveys.

The total cost of point 2 can easily be as high as $ 100.000-150.000.

Exploratory drilling (point 3) requires a first well and perhaps three or four additional wells, in the case of a successful first well.

We must remember that a single productive well does not prove an industrial field. But we must also remember that a single well can be put on production with a little plant and in the same time it will be able to prove the field and produce marketable energy.

The cost of an exploratory well is about $ 150 per meter; henceforth, exploratory drilling can be in the range of a minimum of 150.000 and a maximum of $ 600.000.- for three wells.

Point 4 (probing and evaluating) regards the output measurements and the determination of the working power of the fluids produced by the wells. The cost varies in a great range from field to field and can not be anticipated. It is not very high and it is required only when some industrial success is already obtained.

If the exploration has proven a commercial geothermal field, development and power plant construction will follow. Indications of the costs have been given.

We must emphasize that the point 1 (preliminary survey and selection of a favourable area) is not too expensive. The Governments and the large industrial companies which need energy (also in limited amount) can easily afford the preliminary surveys of the geothermal possibilities; the geothermal energy, with its very low cost, deserves full consideration before a decision about a major power plant is taken.

The Governments will be interested in a general inventory of the geothermal possibilities of their countries, as basic data concerning the agricultural, industrial and mineral development of the country.

5. - Geothermal energy and mineral resources.

Geothermal energy is associated to magmatic bodies intruded in the upper portion of the earth crust. Three types of geothermal fields are so far known; the first type represented by Larderello field, where the geothermal energy is related to a magmatic body without surface volcanic activity. The second type is represented by the Monte Amiata field, which is directly or indirectly associated with an extint Lower Quaternary volcano.

The third type, represented by Wairakei and The Geysers fields, is associated with active volcano.

We will observe that the Larderello field is about 70 km from the nearest extinct volcano, Mount Amiata; Monte Amiata is the northermost volcano of the region of great Quaternary volcanism along the Thyrrenian coast of southern Tuscany and Latium (M. Amiata, Tolfa, Bolsena, Bracciano, Vico Vulcani Laziali, Rocca Monfina). The stock of magma of Larderello is an intrusion which did not originate a volcano for lack of sufficient energy, but its relations with the volcanic framework of the Thyrrenian coastal region are out of discussion,

We can henceforth say that all the recent volcanic regions, with post-pliocene volcanoes, active or extinct, have geothermal possibilities. We point out also that the volcanic regions are often rich in mineral deposits; the Pacific volcanic belt is a classical example.

Geothermal energy can be an economic element of paramount importance in developping the mineral deposits.

6. - Conclusions.

The industrial value of the geothermal energy is no more in the realm of speculation: it is a proven reality. Its cost is competitive with all the other sources of energy; as a matter of fact, it is one of the cheapest, or the cheapest, source of energy.

Geothermal science is still in an initial stage, but in the very last years impressive progress has been made both in exploration and in esploitation; a reduction of cost and risks is resulting and a great expansion of the geothermal industry can be anticipated.

Preliminary investigations concerning the geothermal possibilities are not too expensive and they must be recommended in all volcanic regions of the world; also the areas with quaternary extinct volcanoes offer good possibilities of commercial geothermal fields.

Bibliographical indications

A section of the "United Nations Conference on the New Sources of Energy", held in Rome in August 1961, was dedicated to the geothermal energy. 77 specialized papers were presented by scientists of many countries; the papers covered all fields of geothermal science; they represent an invaluable source of economic, scientific and technological information. Previous literature is abundant, but scattered in many bulletins or rewiews of difficult access; we will mention only the important theoretical papers by J. Goguel, Le régime thermique de l'eau souteraine (Ann. des Mines, X, 1953, p. 3 a 32, Paris) and by G. Bozza, Sull'origine della termalità nelle acque e nel vapore endogeno (1961), privately printed by the geothermal Company "Larderello" in Italian, English and French.

Figures

1. - Geological cross section of the Larderello field (from Stefani, 1962, modified). 1 = Neogene. 2. - Flysch series. 3. - Evaporitic Triassic Series. 4. - Quartzitic Series. 5. - Basement.

2. - Developped and proven areas in Larderello geothermal field (by Burgassi, 1962). The field is not delimited and new producing areas will be discovered by exploratory drilling.

3. - Geological cross section of the Wairakei field (by Grindley, 1961). (1 = Ash showers and Alluvium. 2. - Siltstone and pumiceous sandstone, diatomite. 3. = Pumice breccia, non-welded lapilli crystal and vitric tuff. 4. = Waiora Valley andesite. 5. = Wairakei ignimbrite, dense green-gray quartzose ignimbrite (welded crystal tuff).

Fig. 1 G. FACCA - Geothermal energy exploration

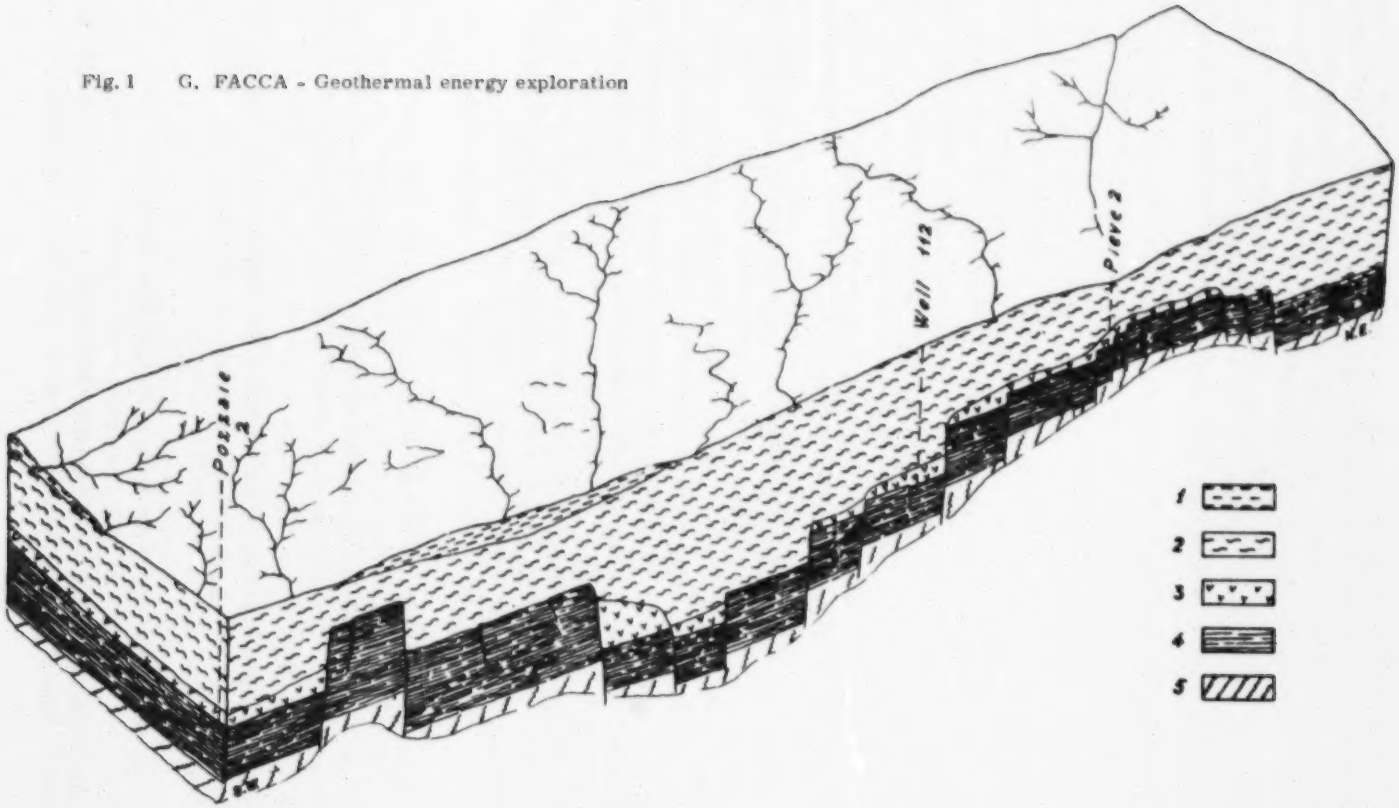
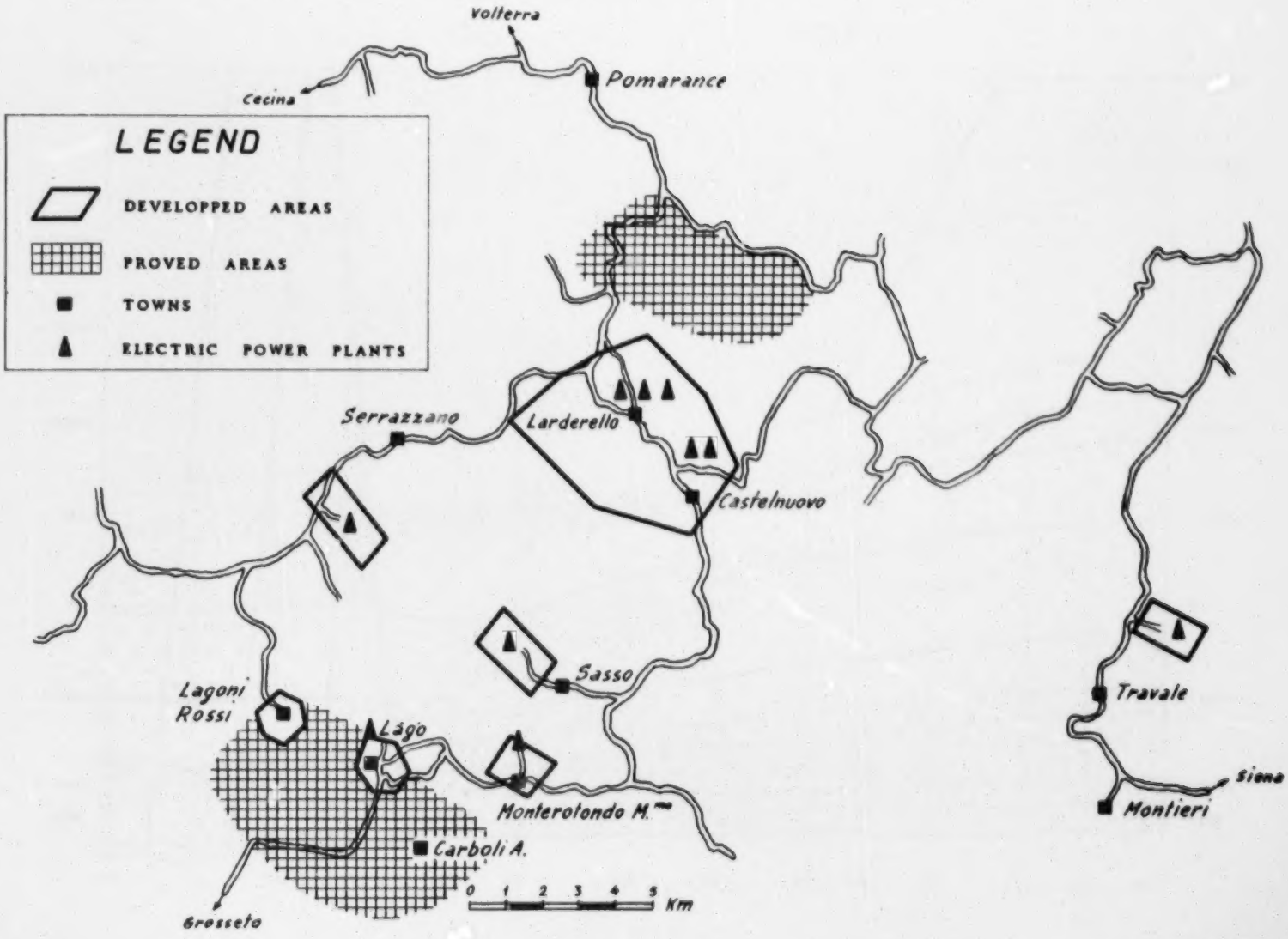
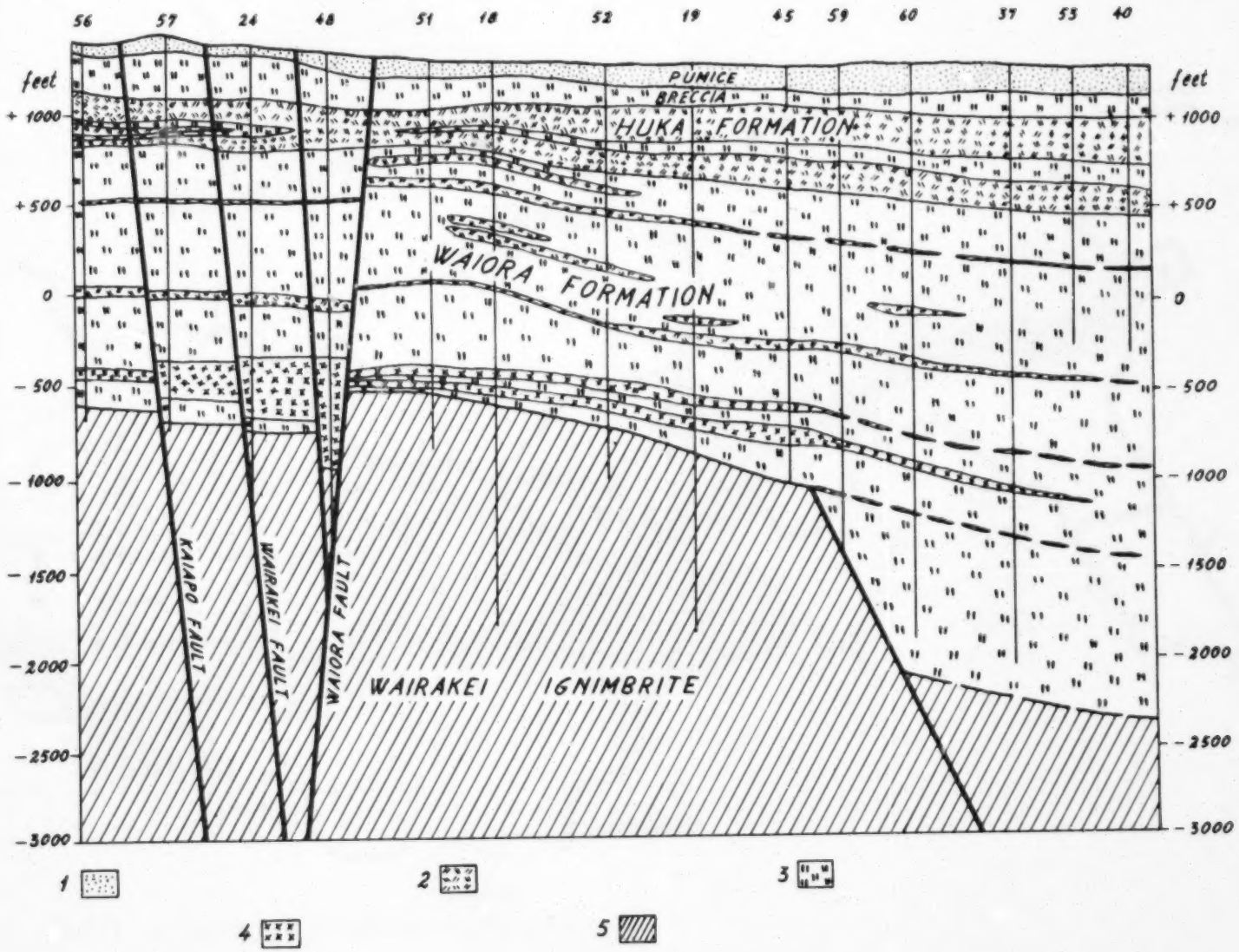


Fig. 2 G. FACCA. - Geothermal energy exploration





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